Electrostatics*

Object

To produce unbalanced static charges and study their nature.

Theory

Most materials that we come across are more-or-less electrically neutral - that is, they have (roughly) equal numbers of electrons and protons. However, when two materials are rubbed vigorously against each other there can be a transfer of surface electrons from one to the other. The direction of transfer depends on the relative binding strengths of electrons in the two materials. As a result of this transfer of electrons, the material that loses electrons develops a net positive charge and the receiver of electrons develops a net negative charge.

For best effects in this experiment, it is clear that the two materials that are rubbed against each other must have a large area of contact. This is achieved by choosing the two materials to be in the form of a solid rod and a piece of cloth. Solid rods and cloths of various kinds will be available in the lab for this experiment.

The measurement methods

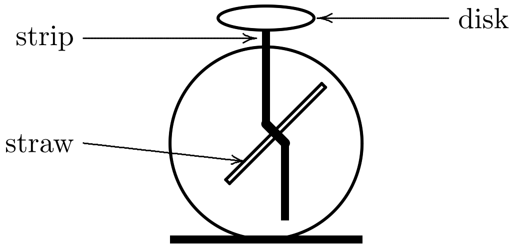
The measurement techniques used for this experiment will be crude but highly instructive due to their simplicity. Students may think of methods of refining these techniques. The two techniques used are as follows.

The electroscope

The electroscope provided has a rigid aluminum strip connected to an aluminum disk. A light straw with an aluminum coating is pivoted on the strip. The strip and the straw are encased in a cylindrical box with transparent plastic windows to protect the straw from outside air movements. When some charge is placed on the disk it distributes over all aluminum parts that it is in contact with†. So the aluminum strip and the straw have the same kind of charge and hence they repel. The repulsion force is large enough to turn the light straw. The amount of turning does depend on the amount of charge; but actual calibration for quantitative measurements is not practical. If a second charge placed on the electroscope makes the straw recede, it is concluded that it has a sign opposite to that of the first and vice versa. This method can be used to classify all the materials you have according to the two possible signs of charge. The actual sign of charge cannot be found by this method unless the sign of charge on at least one material is given.

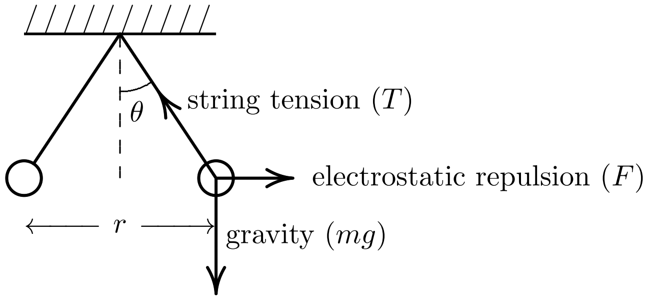
†This is because aluminum is an electrical conductor. The properties of conductors will be discussed in class at a later time.

To discharge the electroscope, touch the disk with your hand. Your body being a rather large conductor, distributes the charge all over itself leaving negligibly little charge on the electroscope.



The string and ball

Although this method cannot give much of an accurate measurement of the magnitude of charge, it provides some idea of how such measurements can be made. It consists of hanging two very light balls (coated with graphite - a conducting material) with strings of equal length from a common point of suspension. If a charge is placed on any one of these two balls, it is distributed equally between the two when they are in contact (as they have conducting coatings). As soon as both balls acquire some charge, they repel each other and rise up. Now each ball can be seen to be in equilibrium under the influence of three forces – string tension, gravity and electrostatic repulsion. The force equilibrium equations and Coulomb's law can be used to determine the charge on each ball.



As the ball is stationary, the total force on it must be zero. Hence, the vertical component of string tension must match the vertically downward gravitational force as shown in the figure above.

$$T \cos\theta = mg,$$

where m is the mass of the ball and g the acceleration due to gravity. Also, the horizontal component of string tension must match the electrostatic force of repulsion.

$$T \sin\theta = F.$$

Eliminating T from these equations gives,

$$F = mg \tan\theta.$$

From Coulomb's law,

$$F = \frac{kq^2}{r^2},$$

where r is the distance between the charges, q the charge on each ball and $k = 9.0 \times 10^9 \mathrm{Nm}^2/\mathrm{C}^2$. Using these equations we can solve for q in terms of the measurable quantities r, θ and m.

$$q = \sqrt{\frac{r^2 mg \tan\theta}{k}}.$$

Directly measuring θ can be difficult. But we note that

$$\sin\theta = \frac{r}{2l},$$

where l is the length of the string.

Some things to do

Using the electroscope one can classify the different materials according to the sign of charge they can acquire. See if the same rod can acquire different charges when rubbed with different cloths. See if you can charge the electroscope without actually touching any of the charged objects to it (Hint: You might need to touch the disk with your hand). For the string and ball setup, the above formula for charge computation can be approximated for small angles ($\tan\theta \simeq \sin\theta$) to give,

$$q \simeq \sqrt{\frac{mgr^3}{2kl}},$$

where, q is the charge on each ball, m the mass of each ball (2.7×10^{-4}kg), g the acceleration due to gravity, r the separation distance between balls (center to center), l the length of each string and $k = 9.0 \times 10^9 \mathrm{Nm}^2/\mathrm{C}^2$.